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Original Article

High-Frequency Jet Ventilation in Nonintubated Patients

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Abstract

OBJECTIVES: High-frequency jet ventilation (HFJV) is a convenient method for providing ventilation during fiberoptic bronchoscopy. We describe an incipient approach of high-frequency jet ventilation via the working channel of a flexible bronchoscope for nonintubated patients who suffer from hypoxemia during bronchoscopy. The aim of this study was to test the efficacy of this incipient approach and determine the possible complications related to it.

MATERIALS AND METHODS: Sixteen patients who had oxygen saturation below 70% that did not resolve with nasal oxygen for 20 s during interventional bronchoscopy were included in the study. High-frequency jet ventilation was administrated via the working channel of a bronchoscope for 3 min. Arterial blood gas circumscriptions were compared before and after jet ventilation.

RESULTS: Oxygen saturation increased to >90% in all patients 30 s after jet ventilation. Mean arterial oxygen saturation pressure increased from 54.84 to 111.98 mmHg with jet ventilation (p=0.0001). Arterial carbon dioxide tension decreased after jet ventilation. The body mass index had no consequential effect on arterial carbon dioxide pressure after jet ventilation in our patients (p=0.1). Complications such as pneumothorax and working channel damage were not observed.

CONCLUSION: High-frequency jet ventilation via the working channel of the bronchoscope is a novel method that can provide optimal ventilation with minimal complications to nonintubated patients suffering from hypoxemia during bronchoscopy. This method also reduces the duration of bronchoscopy procedures.

KEYWORDS: High-frequency jet ventilation, bronchoscopy, hypoxemia, ventilation, arterial oxygen, flexible bronchoscopy

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INTRODUCTION

Fiberoptic bronchoscopy has been widely utilized over the last years in pulmonary medicine for diagnosis and treatment of pulmonary diseases such as pleural tumors, tuberculosis, and lipoid pneumonia [1-3]. Qualified ventilation in sedated patients during bronchoscopy is an issue of utmost consequentiality. Nasal oxygen supply is adequate for maintaining conventional oxygen saturation (So_2) of over 90% in mildly sedated patients. However, when deeper sedation is needed during the procedure, dropping oxygen (O_2) and elevating carbon dioxide (CO_2) pressures as well as acidemia and arrhythmia are the frequent quandaries faced. Different approaches have been introduced for ventilating deeply sedated patients [1]. Conventional mechanical ventilation (CMV) conventionally does not ameliorate O_2 supplementation during bronchoscopy in sedated patients. Therefore, providing ventilation in this setting is vital.

High-frequency jet ventilation (HFJV) is an opportune technique that distributes a minuscule tidal volume with a frequency exceeding the physiologic level of the patient [3-5]. HFJV can be applied via supraglottic [such as laryngeal mask airway (LMA)], transtracheal, or subglottic approaches [6-9]. All of the three methods truncate the expiratory time and linearly increase the pulmonary capillary wedge pressure and greatest sanctioned working pressure.

The supraglottic HFJV provides the most rapid increase in airway pressure. Transtracheal HFJV approach provides the most consistent atmospheric pressure of the fraction of inspired oxygen (FiO_2). However, both methods increase the peril

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of blowing debris, barotrauma, and hypercapnia [5,6]. In comparison with these, complications are minimized with the subglottic approach. Furthermore, PAWP can be observed, and the distributed FiO_2 can be determined. Recently, subglottic HFJV was utilized broadly via different bronchoscope channels. However, the working channel of the bronchoscope (utilized for suction, oxygen distribution, and local anesthesia administration) has not been applied before in any study.

We evaluated a novel technique in nonintubated sedated patients undergoing flexible bronchoscopy (HFJV via the working channel) in this study.

MATERIALS AND METHODS

Study Design

This randomized clinical tribulation study was designed by an expert methodologist. The final study population was estimated to be 10-20 patients. The research project was approved by the ethics committee and review board of Shadid Behehti University of Medical Sciences (IR. SBMU. MSP. REC.1395.218), and ethical clearance conformed to the Declaration of Helsinki. To comply with health indemnification portability, the principle of secrecy of patient information was taken into consideration.

Study Population

In total, 150 patients with asthmatic bronchitis and chronic bronchitis underwent interventional flexible fiberoptic bronchoscopy for diagnosis or treatment during April-August 2016. Patients signed apprised informed consents after the study procedure was explained to them. Intervention operations were routine operative procedures, and none of them were set for clinical research.

Baseline demographic characteristics including age, gender, and body mass index (BMI) were recorded for further analysis. Ecumenical guidelines were utilized in determining the normality of limits [10]. After quantifying the blood pressure and performing electrocardiogram, patients underwent deep sedation using a resilient instauration short-half-life drug (propofol with an infusion rate of 50-75 μg/kg/min; midazolam: 0.02 mg/kg; and fentanyl: 1-2 μg/kg). Sedation status was monitored using a bispectral index of 60. All bronchoscopy operations were conducted using a conventional flexible bronchoscope (BF-1T260, Olympus Tokyo, Japan). The outer and main diameters of the working channel were 5.9 and 2.8 mm, respectively, which comply with the national guidelines [10]. Vital signs and So_2 were monitored and CMV approaches were provided during the procedure.

Patients were further monitored using pulse oximetry for O_2 saturation during the different prep times of each patient for approximately 30-60 min. If SpO_2 decreased below 70% and did not resolve within 20 s of nasal oxygenation, the patient was recommended for study inclusion and HFJV administration. The inclusion criterion was 70% O_2 saturation for 20 s as the borderline (the greatest time of abiding the least saturation). The omission criteria included rigorous cardiac diseases and unstable hemodynamics. Arterial blood sample was accumulated to determine the arterial blood gas (ABG). HFJV (Monsoon, Acutronic Medical Systems AG, Baar, Switzerland) was applied for 3 min via the working channel of the bronchoscope. HFJV was performed with the following parameters: inspiration time of 45%, driving pressure of 3 bar, peak pressure of 80 mbar, FiO_2 of 30%-100%, and frequency (ventilator rate) of 250/min. After applying HFJV for 3 min to obtain an incremented SpO_2 to 90%, second arterial blood sampling was performed, and the bronchoscopy procedure was commenced (Figure 1,2). The arterial blood

Figure 1. Non-intubated sedated patient under HFJV during bronchoscopy with a flexible fiberoptic bronchoscope via the working channel

Figure 2. Jet ventilator catheter

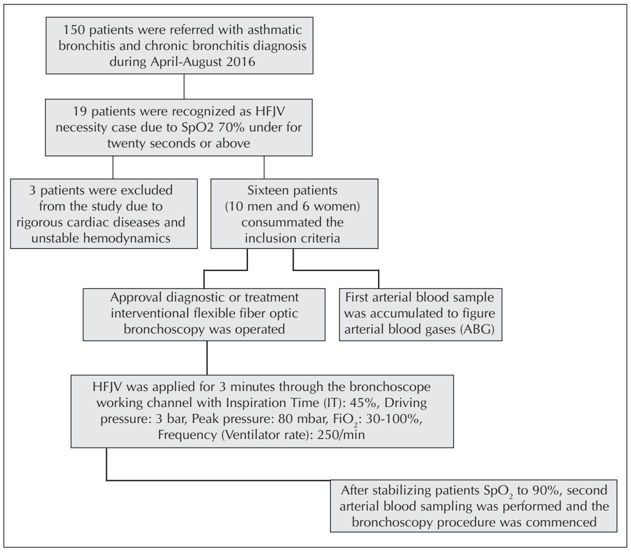

Figure 3. Design of current randomized clinical tribulation study

Figure 4. HFJV connected to the working channel of a flexible fiberoptic bronchoscope

pH was compared in two blood samples. The estimated ventilation efficacy and the availability of oxygen was obtained by comparing the partial pressure of carbon dioxide ($PaCO_2$) (mmHg) and the arterial partial pressure of oxygen (PaO_2) (mmHg) in two samples. The design of the current study is shown on Figure 3.

Statistical Analysis

Data were statistically analyzed using paired t-test and ANOVA using (SPSS) Statistical Package for Social Sciences version 22.0 (IBM Corp.; Armonk, NY, USA). Statistical analyses were conducted following international statistical

Table 1. Baseline demographic characteristics and BMI

Parameters		Values
Age (year) (mean±SD)		56±9.95
Gender (M/F)		10/6
Body mass index (kg/m^2)		31.6±5.5
Cause of intervention procedure		
	Asthmatic bronchitis, no. (%)	7 (44)
	Chronic bronchitis, no. (%)	9 (66)
BMI	NL (%)	12.5
	Overweight (%)	18.8
	Obese (%)	68.8

BMI: body mass index; SD: standard deviation

standards. The perpetual analysis of variables such as age, gender, and BMI were presented as frequency and percentage and mean (±standard deviation) or median (minimum-maximum). Categorical variables were expressed as frequencies and percentages. The variables for between-group differences of the mean were calculated using Student's t-test with significance set at $p<0.05$. Different parameter correlations were resolved using one-way ANOVA correlation coefficient.

RESULTS

Demographics Analysis

The normality of variables was obtained using Kolmogorov-Smirnov test. Sixteen patients [10 males (62.5%) and 6 females (37.5%)] met the inclusion criteria. The patients' age range was 37-75 years, with a mean age of 56±9.95 years. BMI of patients was in the range of 20.8-41 kg/m^2, with a mean of 31.6±5.5 kg/m^2. Two (12.5%) patients showed mundane BMI; 3 (18.8%) patients were inordinately corpulent and 11 (68.8%) were exorbitantly corpulent, according to International World Health Organization (Table 1).

Clinical Analysis

High-frequency jet ventilation increased SpO_2 to more than 95% in less than 30 s in all 16 patients. The analysis of two ABG samples showed that mean $PaCO_2$ decreased from 59.3±6.7 to 52.6±8.09 mmHg after 3 min of jet ventilation. Paired t-test showed that $PaCO_2$ decreased significantly by applying HFJV (p=0.001). Arterial pH also increased from 7.29±0.03 to 7.30±0.04 after jet ventilation. However, these changes were not significant according to the paired t-test analysis (p=0.08). Mean PaO_2 was 54.84 mmHg (PaO_2/FiO_2 ratio<300) before jet ventilation and increased significantly to 111.98 mmHg (P/F ratio~575) with HFJV. (p=0.0001). Partial pressure of carbon dioxide (PCO_2) was 53.2±0.9 mmHg in patients with mundane BMI and 52.3±12.1 mmHg in inordinately corpulent patients. Despite our prospects, no significant differences were observed in PCO_2 in individuals with different BMI status on the basis of one-way ANOVA p=0.1) (Table 2).

Post-procedure Recovery

Leak test was conducted after each procedure to estimate the possible complications associated with HFJV such as tearing of the working channel of the fiberoptic bronchoscope. However, no positive test was reported. To check for pneumothorax as

Table 2. ABG changes after HFJV analysis using paired t-test

Arterial blood gas levels	Before jet ventilation	Post jet ventilation	P
pH (mean±SD)	7.29±0.03	7.30±0.04	0.08
$PaCO_2$ mmHg (kPa) (mean±SD)	59.3±6.7	52.6±8.1	0.001
HCO_3 (mmol/L)			
PaO_2 mmHg (kPa)	54.84	111.98	<0.001 (three digit enough)
PaO_2/F_iO_2 ratio	<300	~575	<0.001
$PaCO_2$ (kPa/mmHg)			
NL	50.9±1.02	53.2±0.0	0.1 (ANOVA)
Overweight	49.1±8.6	52.3±12.1	
Obese			

ANOVA: analysis of variance; pH: power of hydrogen; PaO_2: partial pressure of oxygen in the alveoli (mmHg); $PaCO_2$: partial pressure of carbon dioxide in arterial blood (mmHg); Std. Deviation: standard deviation

another complication of HFJV, we performed chest radiography after the procedure and every 2 h twice. No pneumothorax or other complications attributable to HFJV were observed.

DISCUSSION

High-frequency jet ventilation has been applied during interventional bronchoscopy since 1977. The variable methods of HFJV and the associated complications have been studied. Veres et al. [11] studied HFJV via LMA and achieved qualified ventilation during the procedure. However, they reported mild hypercapnia due to hypoventilation as the most mundane minor unpropitious effect of LMA-HFJV. They also reported that the LMA-HFJV technique resulted in the extension of the bronchoscopy duration due to removal of the bronchoscope and application of the ventilation mask when hypoxemia occurred. In an earlier study, Fernandez-Bustamante et al. [12] applied interventional rigid bronchoscopy connected to a transvector for ventilation; they reported hypercapnia, hypoxemia, and transient hemodynamic changes as the most common complications of this HFJV technique. HFJV has been increasingly utilized using nasotracheal or tracheal catheters via the lateral port of the rigid bronchoscope, via the transtracheal route, or by moving the catheter in the bronchoscope [13-21]. Hautmann et al. [19] studied HFJV using a tracheal catheter; they achieved adequate gas exchange during the bronchoscopy procedure and observed no hypoxia and hypotension. However, hypercapnia was the most common complication during their approach.

The current study aimed to introduce a novel HFJV method to achieve optimal ventilation support and mitigate complications during bronchoscopy. We delivered HFJV via the working channel of a flexible fiberoptic bronchoscope to nonintubated sedated patients who suffer from hypoxemia. To designate a borderline hypoxemia index, the following study design was evaluated: SpO_2 below 75% is the borderline of rigorous hypoxemia and SpO_2 of 65% and below is the index value at which the patient will lose consciousness. Jet ventilation should never be resumed until the airway is open. Considering that mucus clogged the airway in most of our patients, conventional ventilations were applied at the maximum time to open the airway felicitously. Given that vital organs such as the encephalon have 20 s worth of oxygen storage capacity, 70% O_2 saturation for 20 s was designated as the borderline inclusion criterion (the maximum time of abiding the minimum saturation).

Considering the lack of access to capnography, we analyzed ABGs before and after jet ventilation to evaluate ventilation efficacy and possible ventilator setting adjustment needed. $PaCO_2$ was found to be significantly reduced in our study after jet ventilation (p=0.001), whereas PaO_2 significantly increased (p=0.0001). The congruous results favor the efficacy of the current incipient approach, which provides congruous ventilation to patients during bronchoscopy.

A P/F ratio<300 is equivalent to a partial pressure of oxygen (pO_2) <60 mmHg; a P/F ratio<250 is equivalent to a pO_2<50 mm Hg; and a P/F ratio<200 is equivalent to a pO_2<40 mm Hg on room air. The P/F ratio significantly increased after HFJV (p=0.0001). Arterial pH additionally increased after jet ventilation, but the incrimination was not paramount after 3 min in our patients (p=0.08). However, given that most of our patients had chronic respiratory acidosis due to asthmatic bronchitis and chronic bronchitis, the arterial pH results might have been affected.

Generally, PCO_2 reflects the exchange of this gas through the lungs to the outside air. Some degrees of pulmonary diseases with hyperventilation cause pH elevation. Pulmonary edema and acute asthmatic attacks affect lung capacity for freely exchanging CO_2 across the alveolar membrane, thus, leading to high PCO_2 levels.

Additionally, decreased pH is related to ventilation failure and severe degrees of pulmonary diseases. Overweight individuals who are hyperventilating will breathe more rapidly and deeply and will blow off more CO_2, thus, leading to low PCO_2 levels. We hypothesized that HFJV will lead to increased pH in overweight individuals with high BMI. Despite our prospects, differences in PCO_2 value after HFJV in the three variable BMI groups showed no significant differences (p=0.1).

Prolonged foreign bodies result in granulation formation in the field of bronchoscopy. Recently, we utilized HFJV for clearing the bronchoscopy field when perpetuated peregrine body predisposed the field to bleeding during procedures. The current method was used as an auxiliary method in extracting the peregrine bodies. In pediatric patients, HFJV was applied with caution and with low jet ventilation pressure.

The issue of retracting the bronchoscope in hypoxemia duration was resolved by the current approach, and the procedure was diverted. The whole procedure duration was minimized, and the operator working field was not restricted. Our procedures were conducted using a flexible bronchoscope with a working channel diameter of 2.8 mm (Figure 4). We have applied this method in over 100 recent procedures; the reports and results of these procedures will be presented soon. No damages were observed in the bronchoscope with a working channel diameter of 2.8 mm. We also tried ventilation using a bronchoscope with a 2 mm working channel. However, the use of a smaller working channel diameter (<2.8 mm) led to high airway pressure and limited the ventilation. Thus, we do not recommend using HFJV through a working channel with <2.8 mm diameter. Jet ventilation was also ineffective in the working channel when there were too many secretions because this method blew the secretions into the airways and disturbed the ventilation method. Considering that the maximum time of tolerating the minimum saturation of oxygen was selected as the inclusion criteria in the current study, only 16 patients fulfilled the suggested index. A small study group in the current study may have affected our results. Further studies with higher sample sizes are required to offer enough data to confirm the efficacy of the current approach.

The use of HFJV in the working channel of a flexible bronchoscope is suggested to be an effective ventilation technique. This method delivers an open field for intervention tools and provides adequate gas exchange without increasing the risk of barotrauma.

Ethics Committee Approval: Ethics committee approval was received for this study from the Ethics Committee of Shadid Behehti University of Medical Sciences (IR. SBMU. MSP. REC.1395.218).

Informed Consent: Written informed consent was obtained from all the patients who participated in this study.

Peer-review: Externally peer-reviewed.

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